Predictive lighting and perception in archaeological representations

Kate DEVLIN[1], **Alan CHALMERS**[1,2], **Duncan BROWN**[2,3]

[1] *Department of Computer Science, University of Bristol, UK.*
[2]*ArchLight Ltd., UK.*
[3]*Southampton City Heritage, UK.*

ABSTRACT

The current trend for employing three-dimensional computer graphics to represent archaeological sites is limited because their level of realism cannot be guaranteed. The images that are generated may look realistic, but often no attempt has been made to validate their accuracy. In order for the archaeologist to benefit from computer-generated representations and use them in a meaningful way, virtual past environments must be more than pretty pictures — they must accurately simulate all the physical evidence for the site being modelled.

An often neglected facet of reconstructions is the lighting. Standard three-dimensional modelling packages do not allow precise control over lighting values, and as a result, many simulations show the archaeological site under inappropriate or false lighting conditions such as the bright, steady light of the present. Experimental archaeology and realistic lighting simulation allow us to recreate the original lighting of an archaeological site and show it how it might have looked to those who built and used it. Predictive lighting also opens up new avenues of exploring how past environments may have been perceived, allowing us to investigate on a computer new hypotheses about architecture, art, and artefacts in a safe, non-invasive manner.

This paper outlines the need for perceptual realism in virtual heritage, and examines case studies where the application of predictive lighting techniques have enhanced archaeological interpretation.

Keywords: Archaeological reconstruction, realistic computer graphics, visual perception.

1 INTRODUCTION

Current use of realistic three-dimensional computer graphics in archaeology provide the public with a glimpse of the past that might otherwise be difficult to visualise. However, often these images are chosen due to their artistic impact, and have been manipulated to provide the most aesthetically pleasing representation of a site. To date, the emphasis has been on using such images for display purposes, with interpretative and research purposes taking second place to the demand for visually stunning presentation. The pervasive media of television and the Internet, and the public fascination for the past have seen the adoption of computer-generated representations for entertainment and education of the interested layman, rather than as a research tool for archaeologists. For computer graphics to benefit the archaeological community, they must offer the archaeologist the chance to extend or enhance their analysis of a site or artefact. The accuracy of the images produced must therefore be quantifiable — the archaeologist must be confident that what they see in the generated image is comparable to what they would have seen in the original example [Chalmers and Devlin 2002].

One area of realistic simulations that is often neglected is that of the original lighting of a site or artefact. Light cannot be captured in the archaeological record and consequently its importance is rarely considered in interpretations of past environments. The ways in which we view, perceive and understand objects is governed by our current lighting methods of steady, bright electric light or large windows, but in order to understand how an environment and its contents were viewed in the past we must consider how they were illuminated.

Standard three-dimensional modelling software tends to base the lighting conditions on daylight, fluorescent light or filament bulbs and not the lamp and candlelight used in past. In some cases, scenes are illuminated with lighting values that would be impossible in the real world. Realistic lighting simulation must address both the physical interaction of light in a scene and the spectral profile of the light source. With control over this, an accurately-lit representation of an environment can be achieved and the virtual version of an original site or artefact can be manipulated without having to physically touch or harm the real version.

Much has already been discussed on the nature of realistic archaeological representations [Spicer 1988; Reilly 1991; Molyneaux 1992; Reilly 1992; Chalmers et al. 1995; Miller and Richards 1995; Ryan 1996; Daniels 1997; Roberts and Ryan 1997; Gillings 1999; Bateman 2000; Eiteljorg II 2000; Kantner 2000; Chalmers and Devlin 2002] and the dangers of conjecture and artistic licence. This paper deliberately does not debate the merits of realistic graphics, nor does it attempt to define realism. Instead, we provide a framework for creating computer-generated archaeological representations with quantifiably accurate lighting simulation, and show through the use of case studies how this can generate new hypotheses for the archaeologist.

2 ACCURATE ILLUMINATION

Once an archaeological site or artefact has been modelled in a three-dimensional modelling package it must be *rendered*, that is, the colours, textures, light and shading are computed, thus producing the final two-dimensional image from the three-dimensional geometry. In order to obtain an approximation of the original lighting in an archaeological representation, two factors must be addressed in the rendering process. First, the spectral composition of the light — the colour of the light given off by the burning fuel — must match that of the fuel type that would have been used in a specific archaeological instance. Second, the distribution of this light — the path it takes around a scene and the reflections and inter-reflections that occur — must mimic the behaviour of light in the real world.

2.1 Lighting in past environments

The only trace of light in the archaeological record are the methods used to provide it, be they hearths, candles, lamps or windows. In pre-industrial societies, daylight was the regulating factor of the working hours. If we compare that to conditions today, sunlight is far less relevant to how we work [McNamara et al. 1997]. The evidence from architecture tells us the most about lighting — a lack of glass and a need for security often meant smaller windows, therefore dimmer interiors. Going further back in time, the unyielding darkness of a deep cave would require some form of artificial light for navigation purposes alone. It seems plausible that objects and environments were affected by the limitations of lighting, and this influence may have extended into their design. By recreating the means of illumination for a given environment and simulating it accurately, the archaeologist may (literally) find new ways of viewing things.

2.1.1 Creating and measuring the light sources

The type of flames that we wish to model are diffusion wick flames. A typical flame of this nature consists of three parts: the inner core, the blue intermediate zone, and the outer core [Gaydon and Wolfard 1979]. These different zones produce different emissions depending on the fuel type and environment conditions.

The initial step in recreating the light source involves experimental archaeology. In consultation with the Department of Archaeology at the University of Bristol, various types of possible light sources were physically recreated (Figure 1).

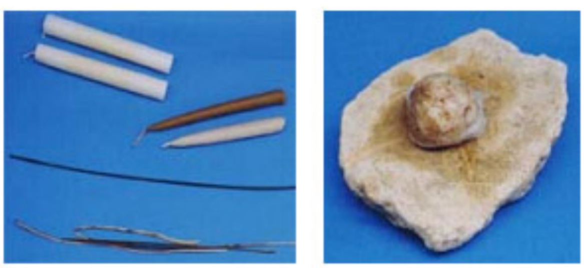

Figure 1: *Experimental archaeology: physical reconstruction of fuel types.*

These included tallow candles (of vegetable origin) and reeds coated in vegetable tallow, a rendered animal fat lamp, beeswax candles (processed and unrefined) and olive oil lamps (one with olive oil only, one with olive oil and salt, and one with olive oil and water).

Each of these fuels produces a different colour when burnt. To obtain this unique spectral profile for each fuel, detailed data was gathered using a spectroradiometer, a device that measures the absolute value of the spectral characteristics without making physical contact with the flame. The spectroradiometer measures the emission spectrum of the light source in the visible bandwidths in 5nm increments, thus providing an accurate breakdown of the flame-light composition of each fuel type. The measurements were all taken in a completely dark room, and the measurements were taken against a diffuse white powder (Eastman Kodak Standard, 99% optically pure). An average of ten readings was calculated for each fuel type.

The resulting luminaire data was converted into red, green and blue (RGB) values to enable display on a computer monitor. These RGB values provide us with the data required during the rendering process to simulate the fuel type of the original light source.

2.2 Predictive lighting

The advent of ray-tracing and radiosity in computer graphics has enabled the simulation of light interaction, providing rendering techniques that mimic the physical behaviour of light in a scene. Despite the availability of physically-based rendering software many users prefer to produce images that are aesthetically pleasing rather than perceptually accurate [Ward 1994]. Also, where the use of predictive lighting software may require some specialist knowledge, access to standard modelling software is often available in a more user-friendly form. In many cases this can lead to problems with the validity of computer simulations where the user may — due to time or varying areas of expertise — lack the skills desired to create a meaningful model, though be fully able to produce an attractive picture.

The rendering package used to create the images for the case studies in this paper is Greg Ward's *Radiance* [Ward 1994]. *Radiance* is a lighting visualisation tool kit that accurately captures luminance and radiances, models a variety of illumination types, supports a variety of reflectance models and supports complicated geometry [Ward Larson and Shakespeare 1998]. The RGB values that have been measured from the original light sources can be used in *Radiance* as lighting values for a computer-generated model, meaning that a scene can be rendered under its appropriate lighting conditions.

2.3 Changes in perception

Conversion of the spectral profile of the illuminants to RGB values for use in a computer simulation does lead to an approximation of the colours present. However, at present this is the most effective method in terms of computational time and efficiency. Even with the approximation, significant perceptual differences related to variations in fuel type are apparent. Psychophysical tests can be used to validate simulations and compare them with real scenes [McNamara et al. 1998; McNamara et al. 2000; Chalmers et al. 2001].

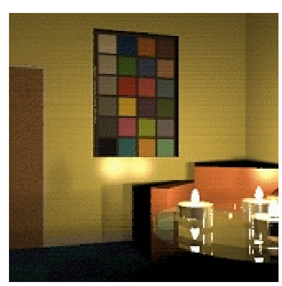

Figure 2: *Simulation with modern 55w lighting.*

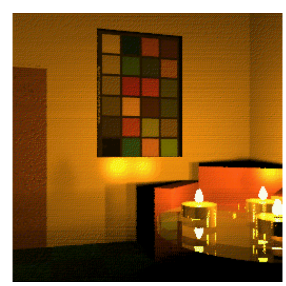

Figure 3: *The same scene under tallow lighting.*

Figures 2 and 3 show a test scene containing a MacBeth colour chart illuminated with modern lighting and light from a tallow candle. The difference in fuel type has a discernible effect on the appearance of the MacBeth chart. Given the type of lighting that would have been used in past environments, this demonstrates the need to investigate sites and artefacts under their original lighting conditions to ensure we see them as they were intended to look.

3 CASE STUDIES

The following case studies demonstrate how predictive lighting can be used to benefit the archaeologist through the development and testing of new hypotheses. All three examples use the techniques described above, with the archaeological dataset taken from, respectively, measurements made by a tape measure, a scale plan, and a laser scanner. All textures were created from photographs, with the inclusion of a colour chart for calibration.

3.1 Medieval House

The initial impetus for work on validated illumination was the question as to how medieval pots would have looked in their original setting [McNamara et al. 1997].

Figure 4: *Examples of medieval pottery.*

This case study considers the ways in which medieval interiors were illuminated and how lighting conditions might affect the ways in which objects were perceived and designed.

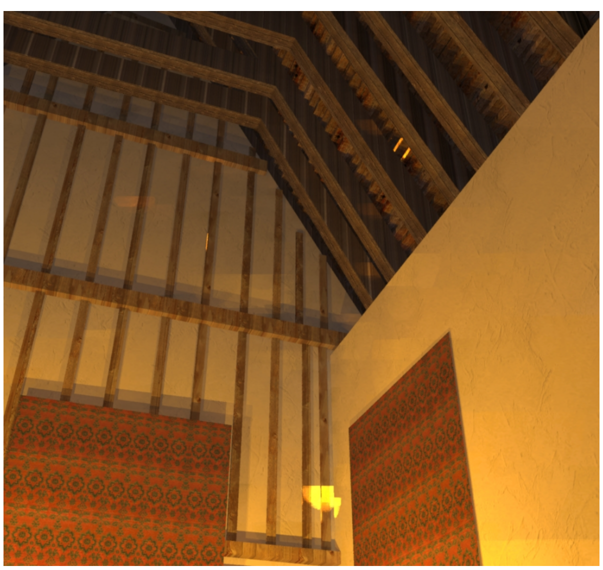

Figure 5: *Medieval house simulation.*

A computer-generated model of the hall of a medieval town house was created. The model is based on the Medieval Merchant's House museum in Southampton, a half-timbered structure renovated by English Heritage as accurately as possible to represent a 13th century dwelling of some economic status.

Figure 6: *Medieval house simulation (elevated view).*

This model allows us to examine the medieval pottery in a close approximation to its original setting (Figures 5 and 6. This reveals details that may bring insight into medieval ways of living. For example, only the top half of some jugs are glazed and decorated, and this is perhaps indicative of how they were illuminated in use, perhaps by daylight through windows or perhaps from torches hung on walls, suggesting many pots would have looked brightest when lit from above (Figure 4).

Even more crucial is the relationship between light and colour. As shown, colours will change in appearance according to the types of light source present. The recreation of medieval lighting conditions is therefore seen as a vital step in comprehending attitudes to colour, and eventually perhaps, shape and decoration. If there is any symbolic meaning in the use of colour on pottery then this might be revealed through an exploration of medieval perception, through the recreation of a medieval environment. The modelling of a realistic environment through the application of computer graphics and psychophysics, is potentially the most far-reaching and flexible way of exploring human perceptions in the past.

3.2 Pompeii Frescoes

For highly-decorative interiors, predictive lighting can be useful in testing how a room may have been laid out or used by the original inhabitants. The UNESCO World Heritage site of the Archaeological Areas of Pompeii, Ercolano and Torre Annunziata contain fine examples of Roman frescoes. The House of the Vettii in Pompeii was chosen for the study, with the work focusing on a reception room off the colonnaded sculpture garden [Nappo 1998]. This room is lavishly decorated in the IV Style (Figure 7) and was chosen due to the rich colours, good state of preservation, and artistic effects such as *trompe l'oeil*, a painting technique that deceives the eye into viewing a two-dimensional image as having three-dimensional structure. The frescoes were recorded photographically, with the

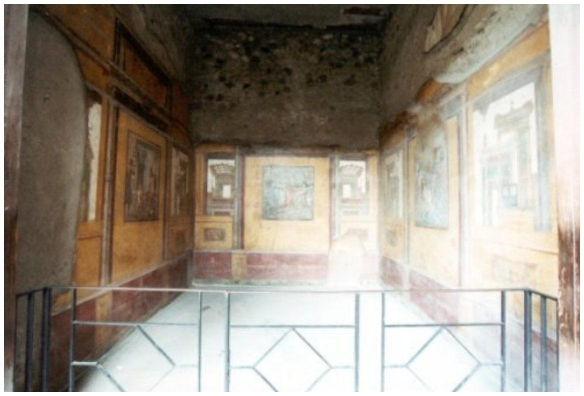

Figure 7: *The room in the House of the Vettii as it appears today.*

use of a colour chart for calibration purposes and to identify illumination levels. A three-dimensional model was generated from a scale plan. The most readily available fuel type for this area was deemed to be olive oil, so the spectral profile of the olive oil lamps was used to illuminate the scene. Also, a technique for including real flame captured from video footage and inserted in the virtual scene gave a realistic appearance to the lamps without having to model the actual flame. Therefore, the virtual scene contained the correct illumination levels for a scene lit by olive oil lamps, with a real flame incorporated (Figure 10). Full details of this work appear in Devlin and Chalmers [2001].

In the resulting images it is plainly demonstrable how the scenes vary depending on how they are illuminated. Under modern lighting conditions (Figure 8) such as we might see today, the colours are not as vibrant as they appear under lamp light (Figure 9). When viewed under olive oil lamp, the red and yellow paint of the frescoes is particularly well-emphasised. Also, the *trompe l'oeil* artwork resembling mock windows and external architecture actually takes on the appearance of a real view to the exterior as the three-dimensional depth cues are increased.

Figure 8: *Simulation viewed under modern lighting.*

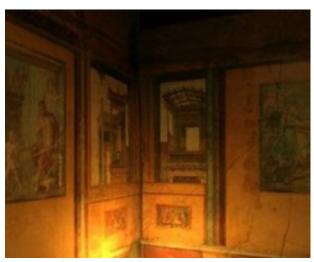

Figure 9: *Simulation viewed under olive oil lamp.*

By changing the number and the positions of the light sources in the room, various effects can be achieved.

It is possible to test how lighting may have been distributed in order to highlight the artwork in the most effective manner. Such positioning of lighting may have determined the arrangement of furniture in a room. Again, such manipulations are possible when working with a virtual version of the scene.

3.3 Cave Art

As a way of illustrating the potential computer graphics has to offer archaeology we consider the prehistoric site of Cap Blanc. The rock shelter site of Cap Blanc, overlooking the Beaune valley in the

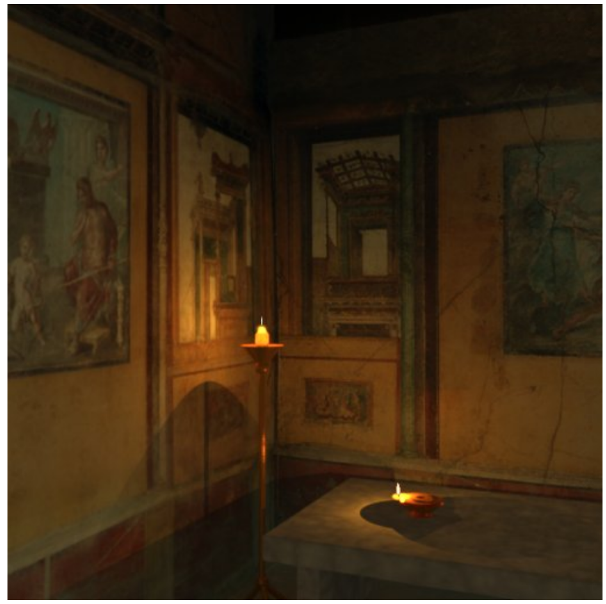

Figure 10: *Simulation viewed under olive oil lamp, with furniture to show shadow effects.*

Dordogne, contains perhaps the most dramatic and impressive example of Upper Palaeolithic haut-relief carving. A frieze of horses, bison and deer — some overlaid on other images — was carved some 15,000 years ago into the limestone as deeply as 45cms, covering 13m of the wall of the shelter. Since its discovery in 1909 by Raymond Peyrille several descriptions, sketches, and surveys of the frieze have been published, but they appear to be variable in their detail and accuracy .

In 1999, a laser scan of was taken of part of the frieze (Figure 11) at 20mm precision [Robson Brown et al. 2001], using an eye safe laser to ensure there was no possibility of damage to the site. Figure 11 shows part of the frieze from Cap Blanc. Some

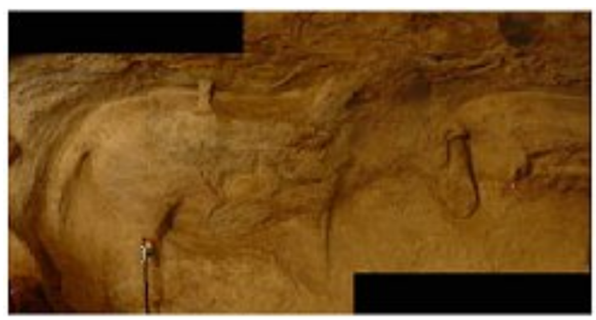

Figure 11: *Part of the frieze from Cap Blanc.*

55,000 points were obtained and converted into a triangular mesh. Using detailed photographs as textures (each with a rock art chart to enable colour calibration) and appropriate lighting values, the model was then rendered in *Radiance*. Figure 12 shows the horse illuminated by a simulated 55W incandescent bulb (as in a low-power floodlight), which is how visitors view the actual site today. In Figure 13 the horse is now illuminated by an animal fat tallow candle as it may have been viewed 15,000 years ago. As can be seen the difference between the two images is significant with the candle illumination giving a warmer glow to the scene, as well as increasing the shadows. The dynamic nature of the flame, and its position

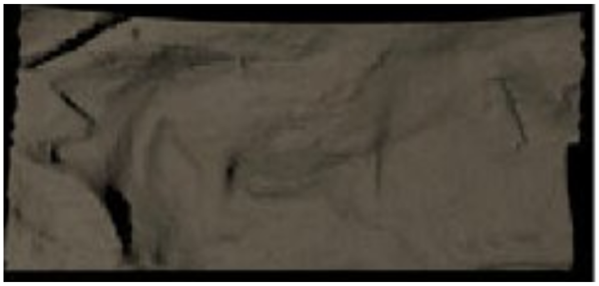

Figure 12: *The simulation under 55w incandescent bulb.*

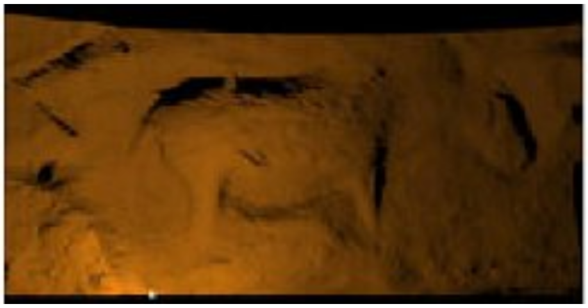

Figure 13: *The simulation under animal fat lamplight.*

in the environment also contribute to changes in perception.

For this site, we wanted to investigate whether the dynamic nature of flame, coupled with the careful use of three-dimensional structure, may have been used by our prehistoric ancestors to create animations in the cave art sites of France, 15,000 years ago. The shadows created by the moving flame do indeed appear to give the horse motion. We will never know for certain whether the artists of the Upper Palaeolithic were in fact creating animations 15,000 years ago, however the reconstructions do show that the effect is certainly possible. There is other intriguing evidence to support this hypothesis. As can be seen in the figures, the legs of the horse are not present in any detail. This has long been believed to be due to erosion, but this does not explain why is the rest of the horse not equally eroded. The possibility exists that the legs were deliberately not carved in any detail, thereby accentuating any motion by creating some form of motion blur. Furthermore traces of red ochre have been found on the carvings. It is interesting to speculate again whether the application of red ochre at key points on the horse's anatomy may also have been used to enhance any motion effects. Again, lighting simulation provides an opportunity to explore such scenarios.

4 THE NEED FOR CONTEXT

The accurate simulation of lighting type and distribution goes some way to quantifying the level of realism in a computer-generated representation, but the image must still be placed in context to avoid misinterpretation. The provision of additional information — metadata — is still necessary.

In a subject such as archaeology where alternative explanations may be equally plausible, the option to move between a number of different interpretations is undoubtedly important. A form of standardisation is most desirable, but rather impractical given the diverse scope of the subject. In the same way that the archaeological evidence on an excavation needs to be recorded as thoroughly as possible, so too does the process used to create the computer-generated representations so that all the factors might be displayed, allowing the user to make up their own mind based on the supporting material. If we strive to provide information about the underlying decisions taken in the creation of our work then our virtual worlds have the potential of being meaningful, useful pieces of information.

Additionally, display factors need to be taken into consideration so that colours and light levels are portrayed effectively, whether the final image is shown on a computer monitor, on an audio-visual display system, or as a printed page [Chalmers and Devlin 2002].

5 CONCLUSIONS

This research into colour and light has shown how easy it is for our own preconceptions to intrude into the ways we view archaeological objects or sites. The aim is to find methods of analysis that could take us beyond those typical questions of chronology and provenance. If the goal of archaeology is to provide insights into the lives of past individuals, communities and cultures then we need to show a greater respect for the things they have left behind and attempt more refined ways of understanding them.

A definitive explanation should never be expected in archaeology. Archaeology by its very nature is dynamic, with new ideas surfacing daily. Visualising a past environment is fraught with difficulties from the outset, so a means of validating computer-generated representations provides an exciting opportunity to explore and test new ideas, with computer graphics becoming as beneficial to the archaeologist as they are to the public.

6 ACKNOWLEDGMENTS

Thanks to Patrick Ledda for the use of his images from the Medieval House project.

References

BATEMAN, J., 2000. Immediate realities: an anthropology of computer visualisation in archaeology. *Internet Archaeology 8*, http://intarch.ac.uk/journal/issue8/bateman_index.html.

CHALMERS, A., AND DEVLIN, K. 2002. *Recreating the Past (SIGGRAPH 2002 Course)*. ACM SIGGRAPH.

CHALMERS, A., STODDART, S., TIDMUS, J., AND MILES, R. 1995. INSITE: an interactive visualisation system for archaeological sites. In *Computer Applications and Quantitative Methods in Archaeology 1994*, BAR International Series 600, Archeopress, J. Huggett and N. Ryan, Eds., 225–228.

CHALMERS, A. G., MCNAMARA, A., DALY, S., MYSZKOWSKI, K., AND TROSCIANKO, T. 2001. *Seeing is Believing: Reality Perception in Modeling, Rendering and Animation*. ACM SIGGRAPH, Aug.

DANIELS, R., 1997. The need for the solid modelling of structure in the archaeology of buildings. *Internet Archaeology 2*, http://intarch.ac.uk/journal/issue2/daniels_index.htm.

DEVLIN, K., AND CHALMERS, A. 2001. Realistic visualisation of the Pompeii frescoes. In *AFRIGRAPH 2001*, ACM SIGGRAPH, A. Chalmers and V. Lalioti, Eds., 43–47.

EITELJORG II, H., 2000. The compelling computer image - a double-edged sword. *Internet Archaeology 8*, http://intarch.ac.uk/journal/issue8/eiteljorg_index.html.

GAYDON, A., AND WOLFARD, H. 1979. *Flames: Their Structure, Radiation and Temperature*. Chapman and Hall.

GILLINGS, M. 1999. Engaging place: a framework for the integration and realisation of virtual-reality approaches in archaeology. In *Computer Applications and Quantitative Methods in Archaeology 1997*, BAR International Series 750, Archeopress, L. Dingwall, S. Exon, V. Gaffney, S. Laflin, and M. van Leusen, Eds., 187–200.

KANTNER, J. 2000. Realism vs. reality: Creating virtual reconstructions of prehistoric architecture. In *Virtual Reality in Archaeology*. Archeopress, Oxford, UK.

MCNAMARA, A., CHALMERS, A., AND BROWN, D. 1997. Light and the culture of medieval pottery. In *Proceedings of the International Conference on Medieval Archaeology*, 207–219.

MCNAMARA, A., CHALMERS, A., TROSCIANKO, T., AND REINHARD, E. 1998. Fidelity of graphics reconstructions: A psychophysical investigation. In *Proceedings of the 9th Eurographics Rendering Workshop*, Springer Verlag, 237–246.

MCNAMARA, A., CHALMERS, A., TROSCIANKO, T., AND GILCHRIST, I. 2000. Comparing real and synthetic scenes using human judgements of lightness. In *Proceedings of the 11th Eurographics Rendering Workshop*, Springer Verlag, 207–219.

MILLER, P., AND RICHARDS, J. 1995. The good, the bad, and the downright misleading: archaeological adoption of computer visualisation. In *Computer Applications and Quantitative Methods in Archaeology 1994*, BAR International Series 600, Archeopress, J. Huggett and N. Ryan, Eds., 19–22.

MOLYNEAUX, B. 1992. From virtuality to actuality: the archaeological site simulation environment. In *Archaeology and the Information Age*. Routledge, London, UK.

NAPPO, S. 1998. *Pompeii: Guide to the Lost City*. Weidenfeld and Nicolson.

REILLY, P. 1991. Towards a virtual archaeology. In *Computer Applications and Quantitative Methods in Archaeology 1990*, BAR International Series 565, Archeopress, K. Lockyear and S. Rahtz, Eds., 133–140.

REILLY, P. 1992. Three-dimensional modelling and primary archaeological data. In *Archaeology and the Information Age*. Routledge, London, UK.

ROBERTS, J. C., AND RYAN, N. 1997. Alternative archaeological representations within virtual worlds. In *Proceedings of the 4th UK Virtual Reality Specialist Interest Group Conference*, R. Bowden, Ed., 179–188.

ROBSON BROWN, K. A., CHALMERS, A. G., SAIGOL, T., GREEN, C., AND D'ERRICO, F. 2001. An automated laser scan survey of the upper palaeolithic rock shelter of Cap Blanc. *Journal of Archaeological Science 28*, 283–289.

RYAN, N. 1996. Computer based visualisation of the past: technical 'realism' and historical credibility. In *Imaging the past: electronic imaging and computer graphics in museums and archaeology*, P. M. T. Higgins and J. Lang, Eds., no. 114 in Occasional Papers. The British Museum, London, November, 95–108.

SPICER, D. 1988. Computer graphics and the perception of archaeological information: Lies, damned statistics and...graphics! In *Computer Applications and Quantitative Methods in Archaeology 1987*, BAR International Series 393, Archeopress, C. L. N. Ruggles and S. P. Q. Rahtz, Eds., 187–200.

WARD LARSON, G., AND SHAKESPEARE, R. 1998. *Rendering with Radiance: The Art and Science of Lighting Visualization*. Morgan Kaufmann, San Francisco, CA.

WARD, G. J. 1994. The RADIANCE lighting simulation and rendering system. In *Proceedings of SIGGRAPH '94 (Orlando, Florida)*, A. Glassner, Ed., Computer Graphics Proceedings, Annual Conference Series, 459–472.

ABOUT THE AUTHORS

Kate Devlin is a PhD student and research member of the graphics group in the Department of Computer Science at the University of Bristol, UK. Her undergraduate degree was in archaeology and she worked as a field archaeologist and site draughtsman for two years before studying for an MSc in Computer Science. Her research interests are realistic archaeological reconstructions of flame-lit environments and accurate display of such scenes. Her personal interests lie in representation and interpretation of archaeological records. She may be contacted at: *Dept. of Computer Science, University of Bristol, Woodland Road, Bristol BS8 1UB, UK.* Email: *devlin@cs.bris.ac.uk* URL: *http://www.cs.bris.ac.uk/~devlin/*

Alan Chalmers is a Reader in the Department of Computer Science at the University of Bristol, UK. He has published over 80 papers in journals and international conferences on very realistic graphics. His research is investigating the use of very realistic graphics in the accurate visualisation of archaeological site reconstructions and techniques which may be used to reduced computation times without affecting the perceptual quality of the images. He is Technical Director of ArchLight, a company dedicated to creating high fidelity computer generated flame-lit environments. He may be contacted at: *Dept. of Computer Science, University of Bristol, Woodland Road, Bristol BS8 1UB, UK.* Email: *Alan.Chalmers@bris.ac.uk* URL: *http://www.cs.bris.ac.uk/~alan/* and *http://www.archlight.co.uk/*

Duncan Brown is the Curator of Archaeological Collections at Southampton City Heritage, UK; a visiting Research Fellow at the University of Southampton, UK; and a freelance medieval pottery specialist who has spent several years digging in Bucks, Northants, Wales, Sussex, Cheshire. He has worked on assemblages from Fyfield Down, Winchester, the Tower of London, Reading, the Mary Rose, Guernsey, Isle of Wight and elsewhere. Duncan specialises in pottery imported from mainland Europe and has taught ceramic analysis at Bournemouth University and archaeological theory at King Alfred's College. Duncan has been co-editor of the newsletter of the Society for Medieval Archaeology, Secretary of the Medieval Pottery Research Group, founder committee member and subsequently chair of the IFA Finds Group. He may be contacted at: *City Heritage Services, Southampton City Council, Southampton, UK.* Email: *duncan@potboiler.fsnet.co.uk*